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THE WIRELESS DETERMINATION OF THE WASHINGTON-PARIS LONGITUDE

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The problem of determining the difference of longitude between two places on the earth's surface involves two distinct processes: an astronomical determination of the local times at the two places by star observations, and an exchange of signals in order to compare these times. The difference in the times, of course, determines the difference of longitude. The astronomical part of the problem has long been regarded as solved; and the telegraph has served as an excellent medium for transmitting the comparison signals. Nevertheless, trans-Atlantic longitude determinations, depending upon time comparisons made by cable, have not been entirely satisfactory, and the conclusion was reached that the cable cannot be relied upon for fine, accurate work.

With the advent of radiotelegraphy, astronomers, pre-eminently those of France, Germany, and Japan, began experimenting with this as a new means of comparing time signals in longitude operations. The French, by 1911, had determined, with the aid of wireless telegraphy, the differences of longitude between a number of European and French colonial points. American astronomers followed these operations closely, and when opportunity offered in 1912, the U. S. Naval Observatory suggested to the French the redetermination, by modern methods, of the longitude separating the Old World from the New.

This longitude campaign, entered upon with enthusiasm by the Observatory of Paris and the Naval Observatory at Washington, terminated about two years ago. Every move was carefully planned months before actual operations began. The instruments employed were of the highest precision, and they were so manipulated as to avoid all known sources of error. Certain innovations were found to be valuable improvements, and the results obtained give evidence of so high a degree of accuracy that the scientific world will look upon this longitude campaign not merely as an epoch-making contribution to this field of science, but as a model for future achievements.

The French began operations by carrying out an experimental longitude determination in order to test the method and ascertain the nature of the difficulties it might be expected to encounter. From Paris to Bizerte, Tunis, the greatest distance over which they had previously carried their operations, is 960 miles. The distance from Paris to Washington is four times as great; and it could not be known in advance how well radio signals could be

transmitted and received over this expanse of ocean. In the spring of 1913, a party of French army and navy officers set up their astronomical instruments near the powerful wireless station at Radio, Va., and in co-operation with colleagues at Paris, began their preliminary experiment. The astronomical instrument they employed was the prismatic astrolabe, which they had used satisfactorily in previous work.¹ The oversea signals, though faint, were sufficiently clear to warrant the beginning of final operations in the following winter.

The first question was whether the Americans and the French should work together, carrying on a single plan of operations, or separately, in two parties, with two distinct series of operations, and arriving at two independent results, the one serving as a check on the other. The latter plan found favor. The French accordingly decided to have at each place an astronomer and a party of radio experts, with such installation as would enable both to work simultaneously and without interruption by the other. This was an advance over ordinary longitude operations, where the astronomer must stop work while comparison signals are being exchanged. The Americans also adopted this plan, but decided further to have an additional astronomical observer at each end so as to double the number of observing hours, and thus secure more astronomical data.

A requisite of ordinary longitude determinations is rapidity of observation, as some sources of systematic error are thereby avoided. One such source of error is that the clock ordinarily employed cannot be relied upon to run with unvarying rate for more than a short period of time. At Washington, however, the standard Riefler clock of the Naval Observatory, sealed in a glass case, is kept in a double-walled underground chamber which is artificially maintained at uniform temperature, thereby protecting the clock from changes of heat and barometric pressure. At Paris the same result is effected by keeping the standard Riefler in an underground chamber over eighty feet deep, so that daily and seasonal changes do not penetrate from the earth's surface. The clocks, under these conditions, are very accurate, and the American astronomers believed that they might safely extend their observing periods as long as desirable without risk of error due to the clocks.

It was further decided to set up the astronomical telescopes on the grounds of the respective observatories, though this placed the astronomers out of direct touch with the wireless operators at Radio and the Eiffel Tower.

Another question was the nature of the astronomical instruments to be employed. It is a principle of the German school of practical astronomy, now widely followed by astronomers, to eliminate errors during the process of observing, rather than to apply corrections for them to the final results.

¹ See the writer's account of the astrolabe in *Engineering News*, Oct. 8, 1914, pp. 754-755, reprinted in the *Scientific American Supplement*, Dec. 12, 1914, and *Popular Astronomy*, Vol. 23, 1915, Feb., pp. 96-100.

Systematic errors are thereby avoided, and the errors entering into the results are all of the accidental class; as these are largely reduced by the multiplicity of observations, the results themselves are rendered more accurate. The ponderable telescopes of the fixed observatory, however admirably adapted to the work for which they are designed, are too much subject to systematic error to make their use advisable in longitude work of high precision. The astrolabe, moreover, was a new and comparatively untried instrument; the observatory officials planning the work therefore decided conservatively to cling to the small portable transit, reversible during the observation of each star, provided with spirit level, and equipped with self-registering transit micrometer. The micrometer reduces the systematic error due to the observer's personal equation, and reversal on each star eliminates systematic error arising from peculiarities of the instrument.²

For several reasons, the Naval Observatory thereupon ordered from the house of Prin, of Paris, two telescopes of the straight type, object glass about 3 inches aperture, similar to those employed by the French, with traveling micrometer operated by motor.

Since frequent reversals involve danger of jarring the instrument and thereby changing its position, notably its azimuth, means were provided for checking the azimuth in the form of meridian marks set upon piers about 150 feet from the instrument. The lenses for these marks were prepared by the makers of the instruments. Special houses with sheet-iron walls were erected to shelter the instruments. Each was provided with side shutters and a divided roof.

Another matter of importance was the kind of stars to be employed, for upon the accuracy of their catalogued positions depends the accuracy of the local times determined by their aid. The stars hitherto employed by the French for obtaining clock corrections were stars the positions of which they had themselves determined by measurements with their meridian telescope at the Paris Observatory. The Americans, not wishing to limit their choice to so small a number, relied upon the stars published in the "American Ephemeris." So far as possible they wished to observe the same stars at both stations, thereby to eliminate errors of star positions and, where this was practical, they chose many stars from the Boss catalogue. At each station the stars were so chosen as to have their deviation in position north and south of the zenith approximately balance, thereby eliminating another class of systematic errors. An exception to this rule were the stars observed for the express purpose of determining the positions of the meridian marks.

Experience in longitude work had shown that the results obtained by a single night's work, however concordant among themselves, were likely

² For a discussion of these matters, see the writer's review of William Bowie's "Determination of Time, Longitude, Latitude, and Azimuth," in *Science*, Vol. 38, 1913, pp. 514-518.

to differ from those obtained by work on other nights. Any plan of operations, to be complete, must look to the elimination of what has been termed the "night error." It is necessary for this purpose to carry on the work over an extended period. The astronomers believed that ten good nights would do. But as a "good night" meant ideal observing weather at both Paris and Washington and conditions of the ether such as would permit easy exchange of radio signals, it was thought that the work could not be completed in less than five or six months. As events proved, such an extension of time was altogether unnecessary, as, owing to the remarkable regularity of the clocks, thirty-nine nights' observations were made available.

Until the introduction of the transit micrometer, it had been customary to eliminate the personal equation by the observers changing places at the middle of the longitude operations. Since experience had shown that the impersonal micrometer, though greatly reducing this source of error, does not do away with it altogether, provision was made for eliminating even the small residual amount by interchange of observers between Washington and Paris.

So much for the method by which the local times were determined. We come now to a discussion of the method by which these times were compared. As the clocks at Paris and at Washington could not be accurately compared directly, the indirect process was resorted to of noting the clock readings at the moments of previously arranged signals. These signals were radio-telegraphic pulsations of the ether excited by the beats of a Leroy clock which was made to actuate the wireless mechanism. The readings of the standard clocks corresponding to the beats of the Leroy clock, coupled with the clock corrections obtained by the stellar observations, furnished material for comparison of the local times.

For further accuracy, the comparisons were effected by the "method of coincidences" commonly employed by astronomers for comparing sidereal with mean time clocks, and for this purpose the Leroy clock was arbitrarily set to keep artificial time, the beats gaining one in every 80 to 100 seconds of the standard clock. The radio expert had only to keep his attention concentrated for the moments when the beats of the Leroy approached coincidence with the beats of the standard clock, each such moment of coincidence affording an observation.

The observations were made both by ear, and photographically, with the aid of an ingenious device, invented by the French, which transformed the clock beats into flashes of light which thereupon left their impression on the photographic film. To eliminate errors of personal equation, which events proved to be of the same order of magnitude as those of the astronomers, the operators at Radio and at the Eiffel Tower, like the astronomers, exchanged places at the middle of the work.

The radio operations served a further purpose in that they furnished

means for computing the speed of propagation of the Hertzian waves. The Paris-Bizerte longitude determination had resulted in a value for this velocity of 136,000 miles per second. The Paris-Washington result is 175,000, somewhat less than the speed of light. Owing to the greatly improved methods and the fine apparatus employed, this result must be regarded as of very high precision; but we may not on that account conclude that the velocity of the Hertzian waves is different from that of light. The explanation for the discrepancy may perhaps be found in the fact that the radio waves, instead of following closely along the earth's surface, follow a broken path into atmospheric regions.

It is interesting to compare the value for the trans-Atlantic longitude obtained by wireless with the values obtained by cable. Reducing the cable values to a common datum, we find that:

the cable of 1866 resulted in	5 ^h 17 ^m	36.s56 \pm 0.s090
“ “ “ 1870	“ “	36.s73 \pm 0.s056
“ “ “ 1872	“ “	36.s79 \pm 0.s051
“ “ “ 1892	“ “	36.s70 \pm 0.s024
giving a mean value		36.69 \pm 0.s050

The French result has not yet been obtained, but the indications are that it will be very close to the value obtained by the American party, viz., 5^h 17^m 36.s658 \pm 0.s0029.